LBNL-60516

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Optimal Combination of Distributed Energy System in an Eco-Campus of Japan

Yongwen Yang, Weijun Gao, Nan Zhou, and Chris Marnay

Environmental Energy
Technologies Division

June 2006

http://eetd.lbl.gov/ea/EMS/EMS_pubs.html

To be published in the proceedings of the Second International Green Energy Conference.

This work described in this paper was funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Distributed Energy Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

OPTIMAL COMBINATION OF DISTRIBUTED ENERGY SYSTEM IN AN ECO-CAMPUS OF JAPAN

Yongwen Yang1, Weijun Gao2**,Nan Zhou3***,Chris Marnay4*****

* The University of Kitakyushu, 1-1, Hibikino, Wakamatsu-ku, 808-0135, Japan, m4641601@hibikino.ne.jp,

** The University of Kitakyushu, 1-1, Hibikino, Wakamatsu-ku, 808-0135,Japan 2, weijun@env.kitakyu-u.ac.jp

*** Lawrence Berkeley National Laboratory, Cyclotron Road,Mailstop 90R4000,Berkeley, CA 94720,USA , NZhou@lbl.gov

**** Lawrence Berkeley National Laboratory1 Cyclotron Road,Mailstop 90R4000,Berkeley, CA 94720,USA ,C_Marnay@lbl.gov

ABSTRACT

In this study, referring to the Distributed Energy Resources Customer Adoption Model (DER-CAM) which was developed by the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), E-GAMS programmer is developed with a research of database of energy tariffs, DER (Distributed Energy Resources) technology cost and performance characteristics, and building energy consumption in Japan. E-GAMS is a tool designed to find the optimal combination of installed equipment and an idealized operating schedule to minimize a site's energy bills. In this research, by using E-GAMS, we present a tool to select the optimal combination of distributed energy system for an Ecological-Campus, Kitakyushu, Science and Research Park (KSRP).

We discuss the effects of the combination of distributed energy technologies on the energy saving, economic efficiency and environmental benefits.

INTRODUCTION

In recent years as a supplement for regular large-scale power generation system, Distributed Energy Resources (DER) system has got more comprehensive attention. This attention is built on the vision that future electric power system will not be organized solely as centralized systems as they are today. One possible adjunct to the traditional paradigm is the microgrid (µGrid), a localized network of DER system matched to local energy demands. Under this background, DER system, such as natural power system (wind, solar) and co-generation, also know as CHP (Combined heat and power), has been developed greatly during the last 20 years.

In order to introduce DER system and improve the environment of energy system, it is necessary to have a study on choosing and designing economically optimal DER systems.

In previous research [1], Distributed Energy Resources Customer Adoption Model (DER-CAM) developed by Lawrence Berkeley National Laboratory in U.S.A has been discussed. However, it is necessary to consider the difference in climate condition and price structure between Japan and U.S.A. Therefore referring to the DER-CAM, E-GAMS programmer was developed with a research of database of energy tariffs, technology cost and performance characteristics, and building energy consumption in Japan. E-GAMS is a tool which used The General Algebraic Modeling System (GAMS) to design methods and tools for finding the optimal combination of installed equipment and an idealized operating schedule to minimize a site's energy bills.

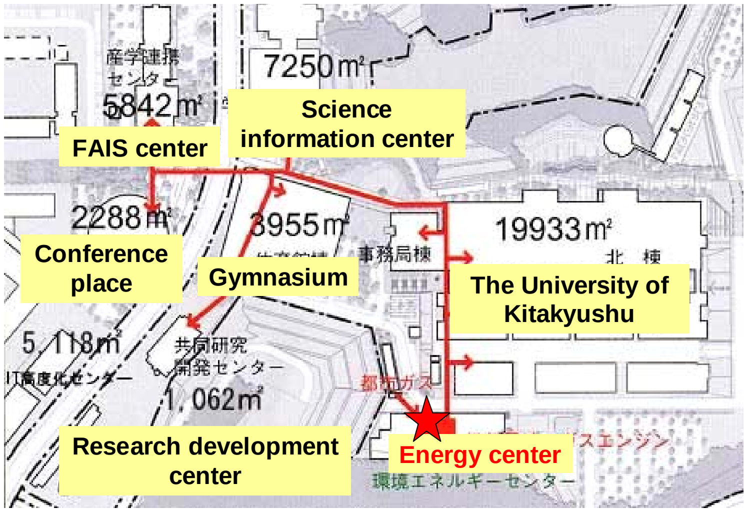

Fig.1. Image chart of energy supply in Ecological-Campus

In this research, as a sample an Ecological-Campus(Figure 1), Kitakyushu, Science and Research Park (KSRP) is selected and five cases of this pattern are utilized to find the optimal combination of installed equipment to minimize a site's energy bills. As a description of energy system of the Ecological-Campus, new energy systems have been introduced. And the energy system not only can supply electricity, but also can recover exhaust heat by absorption chiller or heat exchanger. Figure 2 shows the image chart of energy supply in Ecological-Campus

CONCEPT OF OPTIMIZATION

Firstly, in order to introduce DER system, regional features including demand side、electricity load and heat load, technique and investment must be comprehensively estimated. Figure 2 shows the optimal model. By

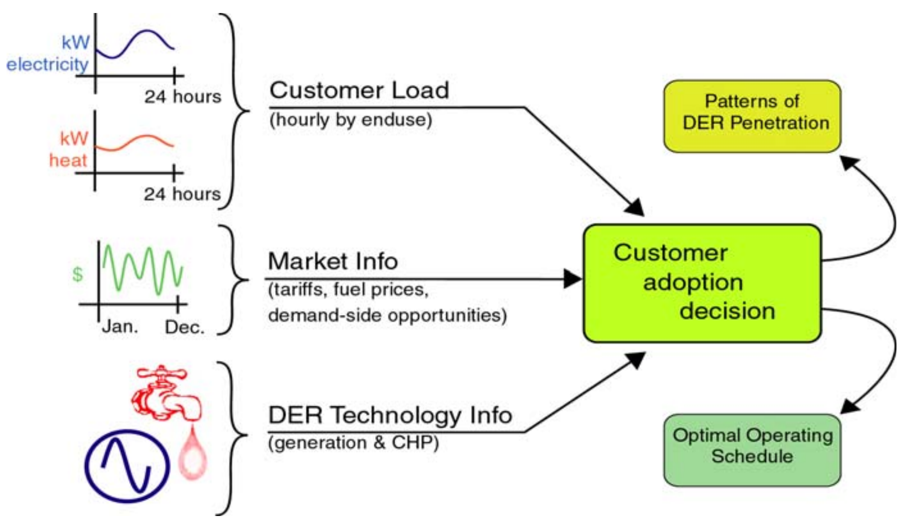

Fig.2. Image chart of E-GAMS model

this model, requirement, market information (gas price and electricity price, etc) and technical information (co-generation, PV, etc.) could be comprehensively estimated to get a customer adoption decision of DER system.

OUTLINE OF GAMS

In generally speaking, GAMS is a high-level modeling system for mathematical programming and optimization. The actual mathematical program is modeled via user-defined algebraic equation. GAMS then compiles them and applies standard solvers to the resulting problem. The features can be mainly described as follows:

1).GAMS lets the user concentrate on modeling. By eliminating the need to think about purely technical machine-specific problems such as address calculations, storage assignments, subroutine linkage, and input-output and flow control, GAMS increases the time available for conceptualizing and running the model, and analyzing the results.

2).Using GAMS, data are entered only once in familiar list and table form. Models are described in concise algebraic statements which are easy for both humans and machines to read.

With the two features, we designed an optimal model as tool for study of DER system by GAMS

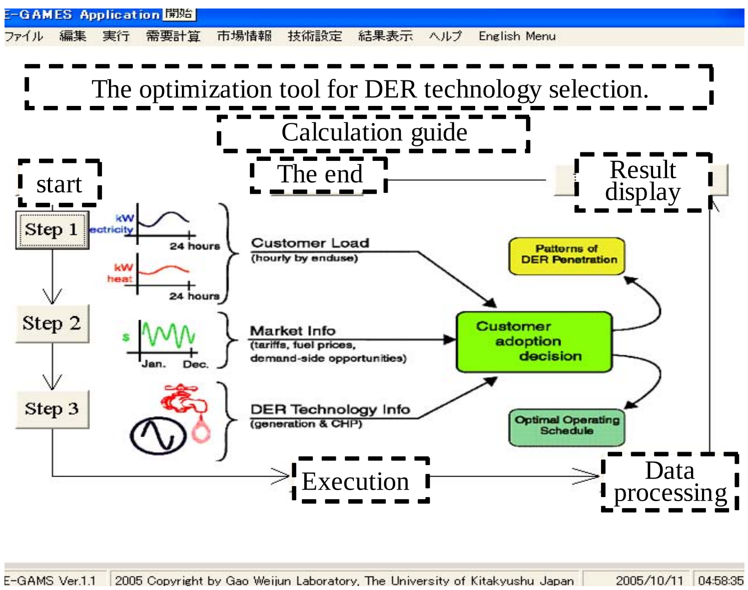

Fig.3.E-GAMS execution menu

OUTLINE OF E-GAMS

Figure 3 shows the execution menu of E-GAMS.

E-GAMS is an optimization tool for DER technology selection. The following could be carried out:

1).E-GAMS minimizes the annual energy cost of a given customer, including DER investment costs, based on input data consisting of DER technology cost and performance, electricity and natural gas tariffs, and end-use energy loads such as space heating, cooling, hot water, and electricity only. E-GAMS reports the optimal technology selection and operation schedule to meet the end-use loads of the customer.

2).The primary energy consumption and carbon emissions resulting are calculated

3). Energy sale price Yen/MJ is calculated.

HYPOTHESIS OF OPTIMAL MODEL

The hypotheses of selected system are shown as follows:

1).The benefit of distributed energy system is from the reducing of electricity rate and gas rate.

2).Owing to the reason of no extra of electric power, we have never considered the limit of technology on electrical power selling system

3).Total power generation only supply to Kitakyushu Science and Research Park (KSRP), not for the other consumer.

4).When demand exceeds supply it is admitted to purchase more power from Power Company.

5).Price and function of equipment are assumed according to what manufactory offer to. Moreover, setting and other cost are not considered in the basic investment.

6).At the same status of technique, the difference of capacity is not to be considered in the economy.

CASE DESCRIPTION AND SETTING OF DATABASE

Case description

In this paper, based on the present model, three cases will be discussed as follow:

Case1 is <u>Do-Nothing</u>: No DER investments are considered. No DER investments are considered. This

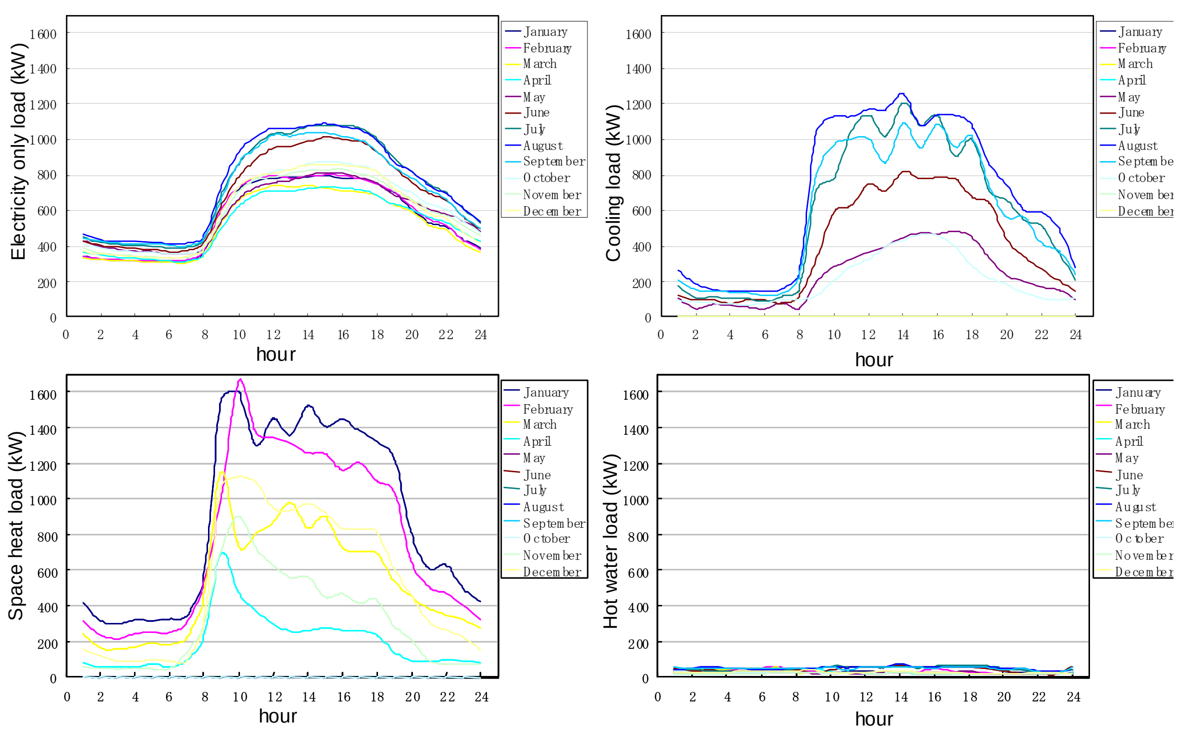

Fig.4. Load Demand of System

scenario provides the annual energy cost, consumption, and emissions prior to DER investment.

Case 2 is DER with CHP: Using E-GAMS to get the optimal technology selection. (Optimal combination)

Case 3 is Case 2 with PV: The case must include PV (150kW * 1). Then Using E-GAMS to get the optimal technology selection.

Case 4 is Case 2 with PV and FC: This case must include PV (150kW * 1) and FC (200kW*1).

Case 5 is current system: The case use current technology selection. PV (150kW*1), FC (200kW*1), GE (160kW*1)

Electricity and Heat Load Demand

In this study, the hourly load demand of 8760 hours for electricity and heat load demand were according to data measured in 2003. Figure 2 shows the measured result of the electricity, cooling, space heating, and hot water loads. Each shows every month loads

Setting of gas price, electricity price

It is clearly that electricity price refer to Kyushu electric power company, just as shown in figure 5. Structure of electricity price is made up of basic charge, daytime unit rate, night unit rate and peak charge. Figure 6 shows the system of gas price. In generally speaking, basic charge is made up of gas basic service fee, fixed fee of gas and maximum season basic charge. ($1＝￥120)

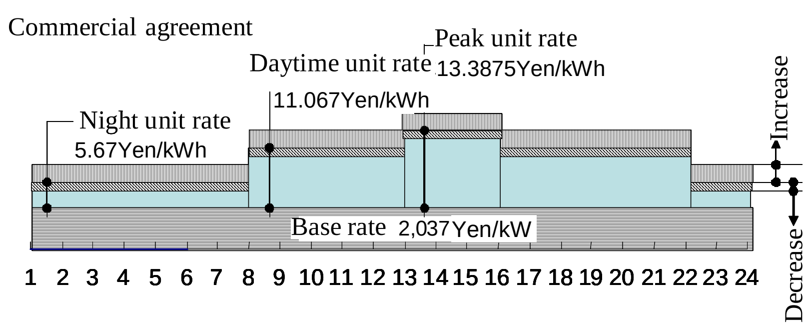

Fig.5. Structure of Electricity Price

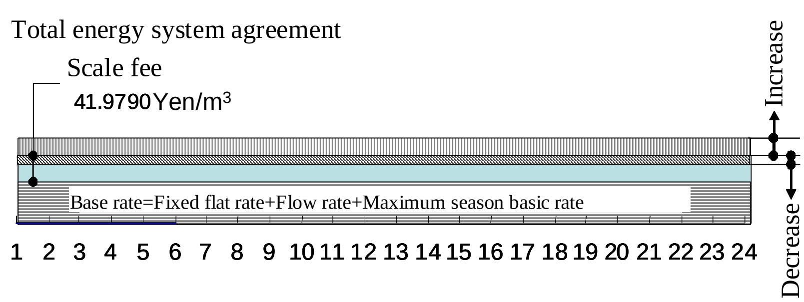

Fig.6. Structure of Gas Price

Table 1.DER Technology Information for the E-GAMS

Name	Capacity (kW)	Lifetime	Capital cost $/kW	Fixed Annual cost $/kW	Variable Annual cost $/kW	Heat Rate kj/kWh	Fuel kind
WindD4-600	600	20	2273	0	0.02	0	0
WindD6-1250	1250	20	2273	0	0.02	0	0
WindD8-2000	2000	20	2273	0	0.02	0	0
Wind15S	1500	20	2273	0	0.02	0	0
WindMD70	1500	20	2273	0	0.03	0	0
WindMD77	1500	20	2364	0	0.03	0	0
WindMM70	2000	20	1909	0	0.03	0	0
WindMM82	2000	20	2000	0	0.03	0	0
PV-10J	10	20	8455	0	0	0	0
PV-20J	20	20	8182	0	0	0	0
PV-30J	30	20	8455	0	0	0	0
PV-50J	50	20	7727	0	0	0	0
PV-100J	100	20	6545	0	0	0	0
GE-200	200	15	2727	0	0.03	11356	0
GE-500	500	15	2727	0	0.03	11392	0
GE-1230	1230	15	2727	0	0.03	9756	0
GT-650	650	15	1091	0	0.01	18182	0
GT-1090	1090	15	1091	0	0.01	14516	0
GT-1500	1500	15	1091	0	0.01	15254	0

Setting of DER Technology Information

Table 1 shows a part of the DER Technology Information for E-GAMS. It is itemized by natural gas engine (GE), gas turbine (GT), micro turbine (MT), fuel cell (FC), and photovoltaic (PV). All equipment (besides PV) can be purchased for electricity generation only, and with heat recovery for heating (HX), or with heat recovery for heating and absorption cooling (ABSHX). Data includes capacity, lifetime (in years), turnkey capital costs, maintenance costs, heat rate, and electrical efficiency.

ANALYSIS OF SIMULATION RESULT

Economic efficiency

Table1 shows the simulation results of cases. The Do-Nothing total energy bill is $1,243,280.As an economically optimal combination, a 500kW CHP natural gas engine and a 500kW natural gas engine were selected, resulting in decreased electricity purchase and increased natural gas purchase. Total annual fuel costs (electricity and natural gas) are reduced by 56% and the total annual energy costs (including the capital and maintenance costs) are reduced by 45%. The payback period is 3.11 years.

For the case 2 and case 3 a 500kW CHP natural gas engine was chosen. Compared with the Do-Nothing case, the total annual energy bill saving are separately 41% with a payback period of 4.98 and 39% with a payback period of 6.56.

The current system Installed capacity is only 505kW, but the installation cost is $190,945, resulting in the reduction is lower and payback period become 44.76 years.

Table2. Simulation result of cases

Case	Installed Capacity	Installed Technology	Annual Cost						Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
			Installation Cost	Electricity Purchased	Gas		Energy Cost	Total Cost			
	(kW)		$	$	For DER	Gas only	$	$	(%)	(%)	Year
Do-Nothing			0	1,154,131	0	89,149	1,243,280	1,243,280			
DER with CHP		CHPGA-K-500									
	1000	GA-K-500	139,176	34,660	407,681	103,155	545,497	684,673	-0.56	-0.45	3.11
PV+(DER with CHP)		PV-150									
		GA-K-500									
		CHPMT--C-60*2									
	1110	CHPGA-K-215	200,867	14,869	423,781	99,477	538,128	738,995	-0.57	-0.41	4.98
FC+(DER with CHP)		PV-150									
		PAFC-200									
		GA-K-500									
		CHPMT--C-60									
	1125	CHPGA-K-215	253,460	20,520	376,796	109,339	506,655	760,115	-0.59	-0.39	6.56
Current system		PV-150									
		PAFC-200									
		CooLCHPGA-K-55									
	505	CooLCHPGA-K-100	190,945	751,186	171,240	76,584	999,011	1,189,956	-0.20	-0.04	44.76

Load composition

Figure 7 shows how five cases meet electricity loads. According to the figure, the compositions of Annual Electricity Generation (kWh) is more than the other compositions in case2 (DER with CHP) and case3 (PV+(DER with CHP)). The composition of PV is about 2~3% in every case which uses PV. As optimal combination case (case2) mainly use the electricity generation from the equipments which are selected by E-GAMS.

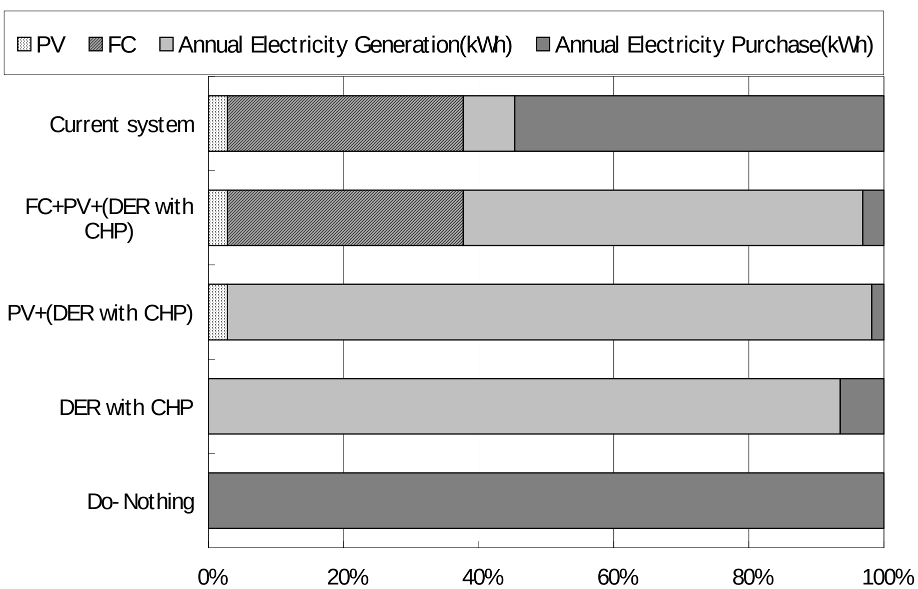

Fig.7.Annual electricity load composition

Figure 8 shows the compositions of Annual cooling load. According to the figure, when the DER+CHP is used, the cooling load is similar to Annual Cooling Load which is met by Natural Gas.

According to figure 9, the compositions of Annual Load of Space Heating which is met by CHP in Annual heat space and hot water load composition are reduced by case3→case2→case4→case5.

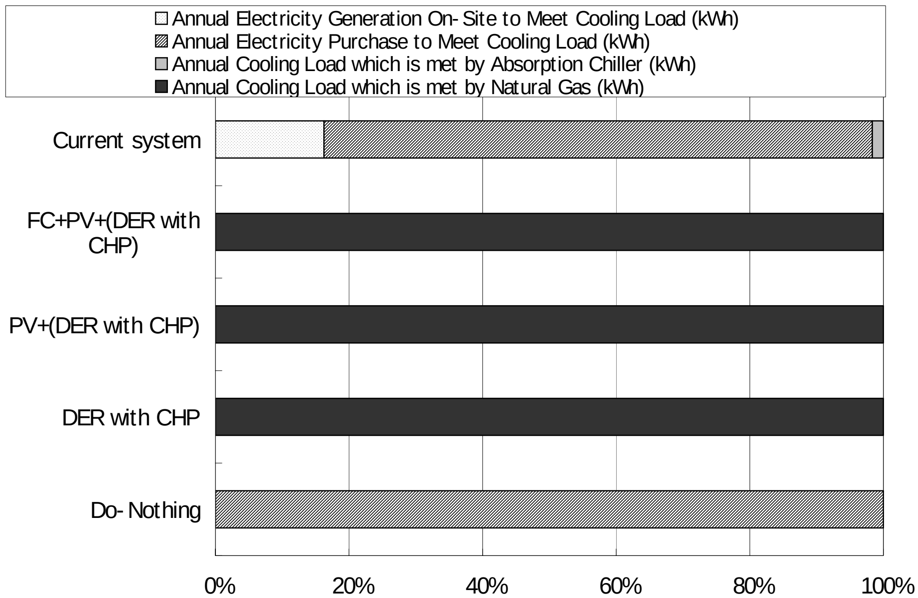

Fig.8. Annual cooling load composition

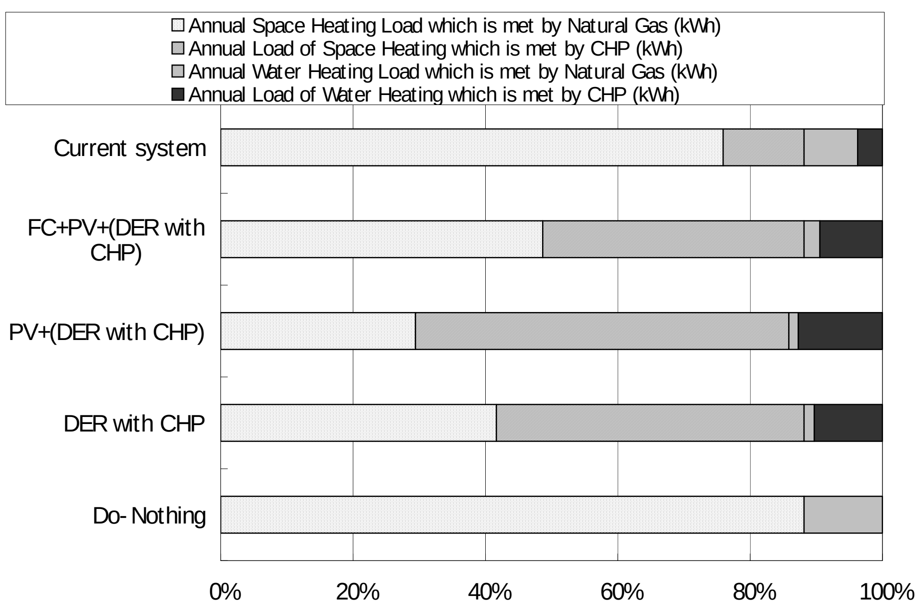

Fig.9.Annual heat space and hot water load composition

Energy consumption, Carbon Emissions and Heat Unit Price

Figure 10 shows the annual primary energy consumption in each case. The primary energy consumption of case1 is larger than the other cases. As energy saving, case4 (PV (150kW*1), FC (200kW*1), GE (160kW*1)) is the most environmentally optimal combination.

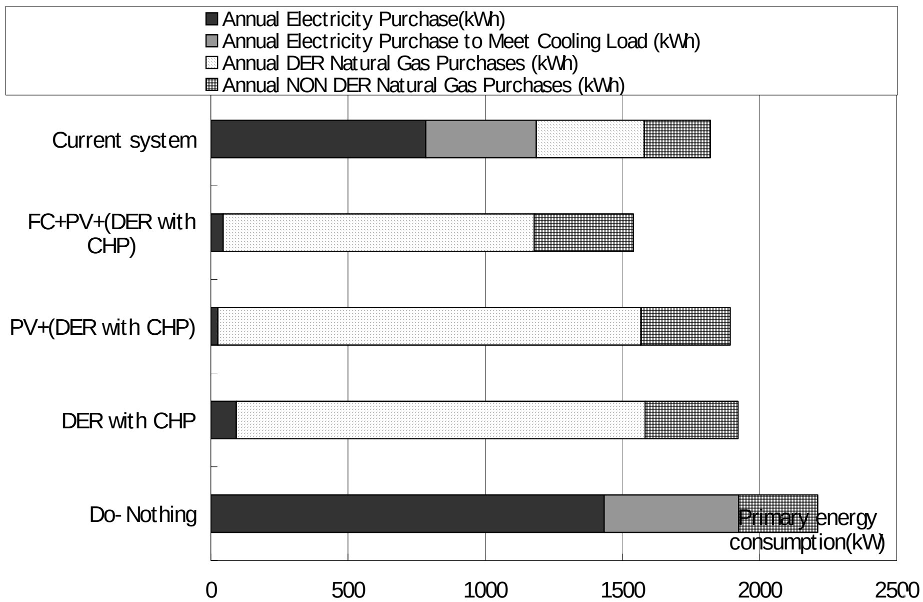

Fig.10.Compare of annual primary energy consumption

Furthermore, carbon emissions resulting from the five cases were analyzed (Figure 10) .It is just like the figure of primary energy consumption. The Annual Off-site Carbon Emissions of case1 is the

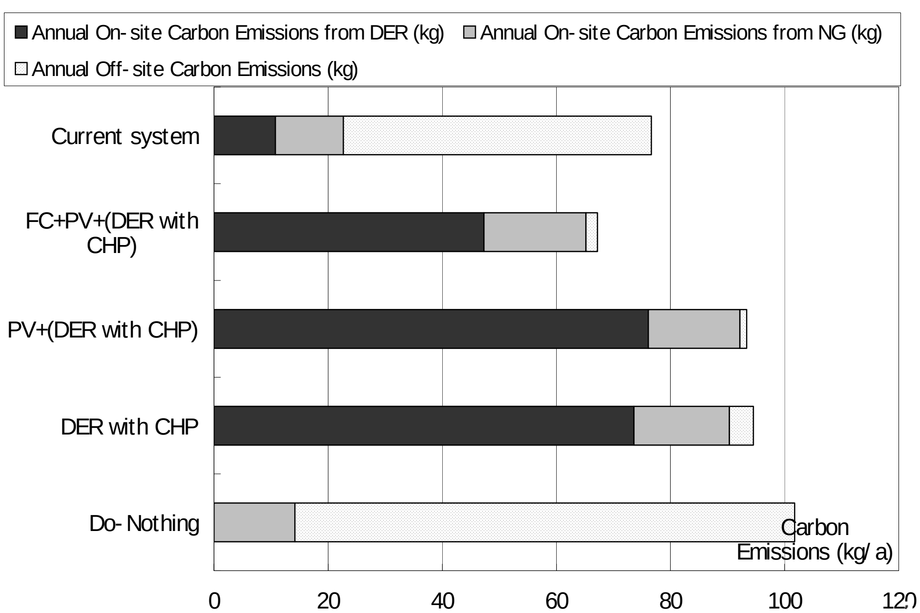

Fig.11.Annual Carbon Emissions

largest one. Carbon emissions for case4 are reduced 27%. For the current case, carbon emissions are reduced by 16%.

The heat unit price comparisons of businesses are shown in Figure 12. According to the calculation result in Table 2, the heat unit price of case2 (Optimal combination) is the cheapest, about 8Yen/kWh (0.067$/kWh), and the current system (case5) is about 16Yen/kWh (0.067$/kWh).

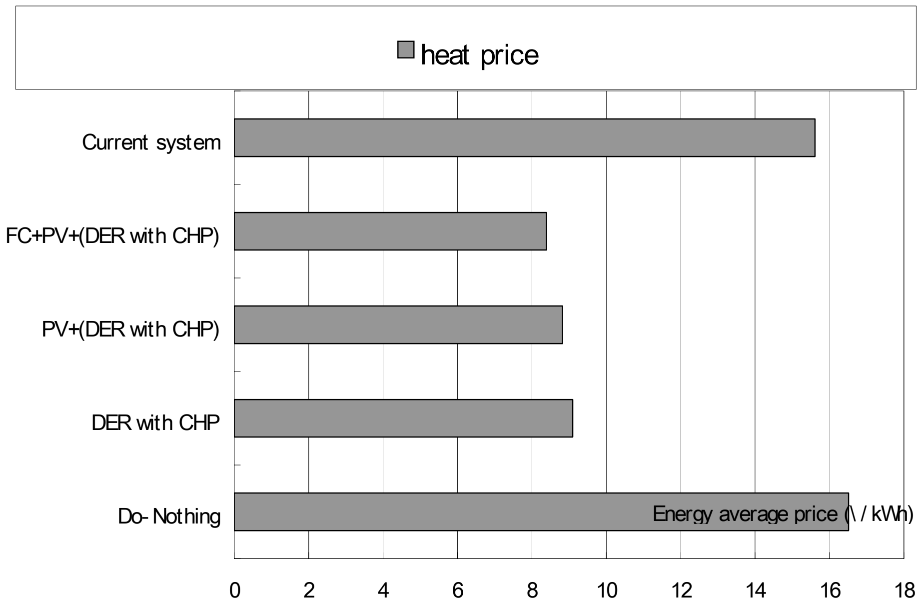

Fig.12.Heat unit price comparisons

CONCLUSIONS

The research used E-GAMS to simulation the five cases. And we discussed the effects of economically optimal DER in this paper. Economically optimal DER investment for each was determined, and the resulting the annual energy cost savings, fuel savings, and carbon emissions reductions are quantified. The economic and environmental effect of DER installation can be seen. Even though these studies conduct cost optimizations, fuel consumption and carbon emissions are noticeably reduced.The results of the simulation can be summarized as follows:

1) As an economically optimal combination (case 2), a 500kW CHP natural gas engine and a 500kW natural gas engine were selected. Total annual fuel costs (electricity and natural gas) are reduced by 56% and the total annual energy costs (including the capital and maintenance costs) are reduced by 45%. The payback period is 3.11 years.

2) As energy saving, case4 is the most environmentally optimal combination. Carbon emissions are reduced 27%

3) The heat unit price of case2 (Optimal combination) is the cheapest, about 8Yen/kWh

Acknowledgement
This research is partly supported by JSPS “Grants-in-Aid for Scientific Research” (KibanC14550591) and the Sasakawa Scientific Research Grant from The Japan Science Society (No.17-269).

REFERENCE

Journal: Chris Marnay,Jennifer L.Edwards,Ryan M.Firestone,Srijay Ghosh,Afzal S.Siddidqui, and Michael Stadler. 2003.Effect of a Carbon on Combined Heat and Power Adoption by a Microgred, 529-530,Sep.,2003 http://eetd.lbl.gov/EA/EMP/.

David Bonilla.2002.A survey on the performance of, and plant manger satisfaction with, co-generation plants in the Japanese manufacturing sector, Second international symposium on Distributed Generation, Oct,2-4,2002,Stockholm, Sweden.

Yingjun Ruan, Bill Batty, Weijun GAO and Ojima.1998.An examination of the yearly energy conservation of co-generation system for apartment, Summaries of technical papers of annual meeting architectural institute of Japan:1083-1084.

Yingjun Ruan, Weijun GAO, etc.2005.Simulation on energy and environment performance of district energy system. Summaries of technical papers of annual meeting architectural institute of Japan.

Weijun GAO, Nan Zhou, Yingjun Ruan.2004. Analysis on tool for conducting an integrated assessment of DER and integration of district system of electrical source and heat source, p.1349, D-2 fascicule.

Book: Anthony Brooke,David Kendrick,Alexander.1999.Meeraus,Ramesh Raman;GAMS user’s guide, http://www.gams.com

Website: http://www.cgc-japan.com/. Accessed on October 10.2005

http://www.kyuden.co.jp/. Accessed on April 10.2005.

http://www.saibugas.co.jp/ryokin/yakkan/s_010.pdf. Accessed on April 10.2005.